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THE COMPUTATION OF RATIONS FOR FARM ANIMALS BY THE USE OF ENERGY VALUES.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY,
Washington, D. C., November 18, 1908.

SIR: I have the honor to transmit herewith, and to recommend for publication as a Farmers' Bulletin, the manuscript of an article on "The Computation of Rations for Farm Animals by the Use of Energy Values," by Dr. Henry Prentiss Armsby. This paper, aside from dealing with the subject in a general way, makes available to the farmer and feeder some of the results of the investigations carried on under Doctor Armsby's direction at the Institute of Animal Nutrition of The Pennsylvania State College in cooperation with this Bureau.

Very respectfully,

A. D. MELVIN,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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The essential working parts of the body contain a great variety of substances, but these may, for our present purpose, be grouped under three heads—water, ash, and protein. The bones, constituting the framework of the body; the ligaments, muscles and tendons which bind together and move the bones; the skin and hair, or wool, which cover and protect the body; the internal organs of circulation, respiration, digestion, excretion, and reproduction; the brain and nerves—in short, the whole mechanism of the body—can be regarded as being composed substantially of these three classes of substances.

Water.—Rarely less than half and sometimes as much as three-fourths of the weight of the live animal consists of water. The proportion of water is greatest in young and lean animals and decreases as they become more mature or fatter.

Ash.—The ash or mineral matter is the portion left after complete burning. Its presence is most familiar in the bones, but it is found in all parts of the body and is just as essential as water or protein. It amounts to from 2 to 5 per cent of the weight of the body.

Protein.—Protein is the name given to a highly important group of substances, of which the white of egg, washed lean meat, the casein of milk, the gluten of wheat flour, etc., are familiar examples. They are composed of the chemical elements carbon, hydrogen, oxygen, nitrogen, and sulphur. They are what are commonly called "organic" substances, which simply means that they may be burned completely in air or oxygen. They differ from the other groups of substances found in the animal body in containing sulphur and especially nitrogen, the latter element constituting from 15 to 18 or 19 per cent of their weight.

Protein is the basis of the living tissues of the body—the so-called protoplasm—and is the substance through which life especially manifests itself. In the body it is always associated with water and ash.

The Reserve Material of the Body.

Fat:—Besides its working parts, the body contains a store of reserve material in the form of fat. While the fat deposits in the body are of use mechanically as cushions between the various organs and as a protecting layer under the skin, nevertheless fat represents essentially a storage of material derived from food consumed in excess of the body's immediate needs. When the food is insufficient or entirely lacking, this store of surplus material is drawn upon, and the animal gradually becomes lean. The percentage of fat in the bodies of agricultural animals may vary greatly, but seldom falls below 6 or rises above 30 per cent.

Glycogen.—Besides fat there are stored up in the muscles, liver, and other organs of a healthy animal rather small amounts of a substance called "glycogen," belonging to the group of carbohydrates described in the next section. Neither fat nor glycogen contains the elements nitrogen or sulphur, but each is composed entirely of carbon, hydrogen, and oxygen.

Composition of the Entire Body.

The average results of analyses shown in the following table indicate the composition of the bodies of different animals in different conditions:

Percentage composition of live animals.

	Ox.			Fat calf.	Sheep.					Swine.	
	Well fed.	Half fat.	Fat.		Lean.	Well fed.	Half fat.	Fat.	Very fat.	Well fed.	Fat.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Water	54.3	50.2	43.6	60.1	56.6	53.7	50.7	44.8	39.0	53.9	42.0
Ash	4.8	4.4	3.9	4.5	3.4	3.3	3.2	2.9	2.8	2.7	1.8
Fat	7.1	14.9	26.8	13.1	8.6	13.2	18.3	28.1	37.2	22.5	40.2
Protein	15.8	15.5	13.7	15.3	15.4	14.8	13.8	12.2	11.0	13.9	11.0
Contents of stomach and intestines	18.0	15.0	12.0	7.0	16.0	15.0	14.0	12.0	10.0	7.0	5.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

COMPONENTS OF FEEDING STUFFS.

Like the animal body, the vegetable feeding stuffs which nourish it contain a great variety of substances, but these, too, like those of the animal, may be classified into a few groups. Not only so, but these main groups are the same as those found in the animal, viz, water, ash, protein, fats, and carbohydrates. The proportions of these ingredients in the animal body and in vegetable substances, however, are widely different.

Protein and Fat.

Protein is the predominant ingredient, aside from water, in the animal body, while the latter stores up its reserve material in the form of fat with but little carbohydrates (glycogen). Protein is also contained in all plants and, as in the animal, forms the basis of the living tissues, but the predominant ingredients as regards quantity are the carbohydrates. In the form of cellulose, or "crude fiber," they form the cell-walls of the plant, while as starch and sugar they are stored up in large amounts in the cells of seeds and roots as reserve material. A few plants, like flax and cotton, store up oil instead of starch and are likewise rich in protein, but as a rule the common feeding stuffs contain relatively small amounts of protein and fat and are rich in carbohydrates.

The protein and fats of plants are not widely different from those of animals and call for no special description here.

Carbohydrates.

The carbohydrates, as starch, sugar, etc., constitute a distinct group, represented in the animal chiefly by the small amounts of glycogen mentioned on page 6 and by the sugar of the milk. They are composed of the chemical elements carbon, hydrogen, and oxygen, the two latter being present in exactly the same relative amounts as in water. Like the fats, they contain no nitrogen or sulphur, but they differ from the fats in containing less carbon and more oxygen.

The carbohydrates of feeding stuffs may be divided into two classes. The first of these includes those substances which are found in the cell walls and constitute the framework of the plant. This class includes cellulose and a great variety of other substances, most of which are rather difficult to dissolve. The "crude fiber" obtained in the analysis of feeding stuffs represents this class of carbohydrates.

The second class of carbohydrates consists of the reserve material stored up in the cells and includes starch, the various kinds of sugar, and other less familiar substances. Some of these carbohydrates, like the sugars, dissolve in water and all may be converted into soluble forms rather easily. In analyses of feeding stuffs they are contained in the "nitrogen-free extract" which, however, also includes a variety of other substances of ill-defined nature.

Average Composition of Feeding Stuffs.

The following table shows the average composition of a considerable number of American feeding stuffs. In this table the common practice has been followed of dividing the group of carbohydrates into two portions. The "crude fiber" or "woody fiber" is stated

separately, partly because it is of somewhat inferior nutritive value and partly because it gives some indication of the bulkiness and woodiness of the feeding stuff. The column headed "nitrogen-free extract" includes all the carbohydrates except the crude fiber—that is, the sugar, starch, etc.

Average composition of feeding stuffs.

[From Farmers' Bulletin No. 22, revised edition.]

Feeding stuff.	Water.	Ash.	Crude protein.[a]	Carbohydrates.		Fat (ether extract).
				Crude fiber.	Nitrogen-free extract.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Green fodder and silage:						
Alfalfa	71.8	2.7	4.8	7.4	12.3	1.0
Clover—crimson	80.9	1.7	3.1	5.2	8.4	.7
Clover—red	70.8	2.1	4.4	8.1	13.5	1.1
Corn fodder	79.3	1.2	1.8	5.0	12.2	.5
Corn silage	74.4	1.5	2.2	5.8	15.0	1.1
Hungarian grass	71.1	1.7	3.1	9.2	14.2	.7
Rape	85.7	2.0	2.4	2.2	7.1	.6
Rye fodder	76.6	1.8	2.6	11.6	6.8	.6
Timothy	61.6	2.1	3.1	11.8	20.2	1.2
Hay and dry coarse fodders:						
Alfalfa hay	8.4	7.4	14.3	25.0	42.7	2.2
Clover hay—red	15.3	6.2	12.3	24.8	38.1	3.3
Corn forage, field cured	42.2	2.7	4.5	14.3	34.7	1.6
Corn stover, field cured	40.5	3.4	3.8	19.7	31.5	1.1
Cowpea hay	10.7	7.5	16.6	20.1	42.2	2.9
Hungarian hay	7.7	6.0	7.5	27.7	49.0	2.1
Oat hay	16.0	6.1	7.4	27.2	40.6	2.7
Soy bean hay	11.3	7.2	15.4	22.3	28.6	5.2
Timothy hay	13.2	4.4	5.9	29.0	45.0	2.5
Straws:						
Oat straw	9.2	5.1	4.0	37.0	42.4	2.3
Rye straw	7.1	3.2	3.0	38.9	46.6	1.2
Wheat straw	9.6	4.2	3.4	38.1	43.4	1.3
Roots and tubers:						
Carrots	88.6	1.0	1.1	1.3	7.6	.4
Mangel-wurzels	91.2	1.0	1.4	.8	5.4	.2
Potatoes	78.9	1.0	2.1	.6	17.3	.1
Rutabagas	88.6	1.2	1.2	1.3	7.5	.2
Turnips	90.6	.8	1.3	1.2	5.9	.2
Grains:						
Barley	10.9	2.4	12.4	2.7	69.8	1.8
Corn	10.9	1.5	10.5	2.1	69.6	5.4
Corn-and-cob meal	15.1	1.5	8.5	6.6	64.8	3.5
Oats	11.0	3.0	11.8	9.5	59.7	5.0
Pea meal	10.5	2.6	20.2	14.4	51.1	1.2
Rye	11.6	1.9	10.6	1.7	72.5	1.7
Wheat	10.5	1.8	11.9	1.8	71.9	2.1
By-products:						
Brewers' grains—dried	8.0	3.4	24.1	13.0	44.8	6.7
Brewers' grains—wet	75.7	1.0	5.4	3.8	12.5	1.6
Buckwheat middlings	11.8	4.8	28.0	6.3	41.9	7.2
Cotton-seed meal	8.2	7.2	42.3	5.6	23.6	13.1
Distillers' grains—dried—						
Principally corn	7.0	2.0	29.2	11.0	39.4	11.4
Principally rye	6.8	2.1	17.3	12.3	54.0	7.5
Gluten feed—dry	8.1	1.3	23.2	6.4	54.7	6.3
Gluten meal—Buffalo	8.2	.9	24.5	6.1	47.8	12.5
Gluten meal—Chicago	8.1	1.0	28.3	1.1	50.8	10.7
Linseed meal—old process	9.2	5.7	32.9	8.9	35.4	7.9
Linseed meal—new process	9.9	5.6	35.9	8.8	36.8	3.0
Malt sprouts	10.2	5.7	23.2	10.7	48.5	1.7
Rye bran	11.8	3.5	14.7	3.3	63.9	2.8
Sugar-beet pulp—fresh	89.9	.4	1.0	2.2	6.3	.2
Sugar-beet pulp—dried	6.4	3.3	10.8	19.8	58.4	1.3
Wheat bran	11.9	5.8	15.4	9.0	53.9	4.0
Wheat middlings	11.8	4.8	28.0	6.3	41.9	7.2

[a] Total N × 6.25.

THE ANIMAL BODY AS A MACHINE.

Mechanically the body of an animal is a very wonderful machine, but what is of peculiar interest in this connection is that the body is what the engineer calls a prime motor—that is, like the steam or gasoline engine, it moves itself and may supply power to move other machines. In fact, there is in some respects a very close likeness between the animal body and what are known as internal-combustion motors, i. e., those engines in which power is developed by burning liquid or gaseous fuel (gasoline, alcohol, producer gas, etc.) in the cylinder of the engine itself. Such an engine requires two things for its operation: (1) Sufficient repair material to keep its working parts in running order, and (2) a supply of fuel in proportion to the work to be done. Just these same two things are what the animal requires—repair material and fuel.

In one respect, however, the animal body differs from the artificial machine—it can not be stopped and started again at will. As long as the animal lives the vital machinery is in operation, although less actively at some times than at others. The animal might be compared to an automobile whose engine must be kept running at a low speed in order to have the power available when needed. Consequently, the animal requires to be supplied with repair material and with fuel as long as it lives and not merely when it is in active use.

That the feed of the animal is its source of both repair material and fuel is sufficiently obvious. We do not need a physiologist to tell us that when an animal is deprived of food its tissues waste away while its fat is burned up in the effort to keep the bodily machinery in motion. We may proceed at once, therefore, to consider the feed in these two relations.

The Demand for Repair Material.

The repair material for any machine must be of the same kind of which the machine is made. We have just seen that the machinery of the body is composed of protein, ash, and water. These, then, are the materials which must be supplied to keep it in repair.

Water, of course, is or should be abundantly supplied in the drink and scarcely need be considered in a discussion of rations.

Ash.—The ash supply has received less attention in the past than its importance deserves. In the ordinary operation of the bodily machinery its ash ingredients are being continually excreted and the food must supply ash sufficient in amount and of the right kinds to make good the loss, while the growing animal needs an additional supply for building up its new tissues. Fortunately, normally constituted rations appear to be rarely deficient in ash. Usually it is only when large amounts of certain by-product feeds are used or

when there is a misrelation between grain and coarse fodder that special attention needs to be given to the ash supply.

Protein.—The protein supply, on the other hand, calls for careful consideration. Protein is the characteristic ingredient of the animal mechanism, and is broken down and destroyed in its operation at a fairly regular rate. Moreover, since the bodily machinery is running all the time, whether any external work is done or not, this loss is continually going on.

The body differs from a machine in being self-repairing, but it can not manufacture protein for repair purposes out of the carbohydrates and fats of its feed any more than it is possible to make repairs for an automobile out of the gasoline which supplies the power. For its protein the body is absolutely dependent on the protein of the feed. This protein is needed for two purposes.

First. It is required for repair purposes in the strict sense; i. e., for making good the wear and tear of the bodily machinery. The amount needed for this purpose is comparatively small, and is no greater under normal conditions when the animal is doing work than when it is not. Like a good engine, the body makes relatively small demands for repair material and requires chiefly fuel.

Second. Protein as well as ash is needed in the growing, pregnant, or milking animal to furnish the material for enlarging the working machinery of the body of the animal itself or of its young. The amount of protein required for this purpose is just so much in addition to that needed for repair purposes simply, and hence the feed of these animals must contain a more liberal supply of this ingredient. This is important physiologically to secure proper nutrition of the young and economically because the growth or milk produced is the principal object of the feeder.

Feed as a Source of Repair Material.

For the reasons stated on page 9, the ash has generally been omitted from consideration in discussing the feed as a source of repair material.

The value of a feeding stuff as a source of protein to the animal body evidently depends in the first place on the amount of protein which it contains. Cotton-seed meal, carrying some 43 per cent of protein, is evidently, other things being equal, a better source of protein than Indian corn, carrying about 10 per cent.

In the second place, however, the protein of the feeding stuff must be capable of being digested by the animal. Of two feeding stuffs containing equal amounts of protein, that one is the more valuable as a source of supply in which the larger proportion of the protein is digestible. The second column of the table on page 15 shows the

average percentage of digestible protein contained in a number of the more common feeding stuffs. These figures are the average results of a considerable number of analyses of the feeding stuffs and a smaller number of determinations of their digestibility. Individual samples may vary more or less, and sometimes considerably, from the average.

A third question is at once suggested, viz, whether the digestible protein from different feeding stuffs is equally valuable to the animal. It is unlikely that this is *exactly* the case, but whether these probable differences are of much practical significance, especially in rations containing a number of feeding stuffs, seems doubtful. At any rate, the only course open at present is to assume them to be of substantially equal value.

The Demand for Fuel Material.

Since the animal machinery is running continually, it requires a continual supply of fuel material, the amount which is necessary depending upon the amount of work done. This fuel material consists chiefly of the carbohydrates and fats of the food, although if more protein be fed than is required for repair and construction purposes it, too, may be used as fuel, while the worn-out portions of the protein tissues are also utilized—that is, the bodily engine can burn up its own waste products as fuel. The unnecessary use of protein as fuel material, however, is wasteful, because protein is ordinarily more expensive to buy or to produce on the farm than are carbohydrates and fats.

If the fuel materials supplied in the food are just adequate to the work to be done, they are virtually burned up as a source of power. If more are supplied than are immediately needed, the body is able to store away the surplus for future use, much as we may fill up the gasoline tank of an engine. To a small extent the body stores up carbohydrates (in the form of glycogen), but most of its surplus fuel it converts into fat. The fat of the body, therefore, is its reserve of fuel. In fattening, the body is accumulating a surplus against future needs which man diverts to his own use as food. If the feed becomes insufficient, this store is drawn upon and the animal gradually becomes lean. Similarly, in growth and in milk production, the animal sets aside a part of the supply of both repair and fuel material in its food for its own growth or for the use of its young, and man appropriates the resulting meat or milk as repair and fuel material for his own body.

Feed as a Source of Fuel Material.

We can run an engine with various kinds of fuel. For the steam engine we may use coal or wood or petroleum; for the internal-com-

bustion motor, gas, alcohol, or gasoline may be employed. Similarly, we supply the animal body with a great variety of feeding stuffs from which it has to extract its supply of fuel, and even the materials which it actually burns up are of various sorts.

These fuel materials are not all of equal value. A pound of good anthracite coal, for example, is, other things being equal, about 14 per cent more valuable as fuel than the same weight of alcohol, while a pound of fat in the food has over twice the fuel value of a pound of starch. Evidently, it will greatly simplify comparisons of different feeding stuffs and rations as sources of fuel material to have some simple method by which we can learn not only the amount of fuel material which the feed contains, but also the quality of that fuel. Such a basis of comparison is afforded by a study of the energy values.

Measurement of Energy.

Anything which has the capacity to do work is said to possess energy. Hence we say that the fuel of the engine and the feed of the animal possess energy, since they enable the engine or the body to do work. They hold this energy stored up in the "latent" or "potential" form of chemical energy. When they are burned in the engine or the body, this chemical energy is set free, part of it being converted into work and the rest escaping as heat.

Plainly, then, the value of a fuel, or of a feeding stuff so far as it serves as fuel, depends, in the first place, on how much chemical energy it contains. This can be measured without difficulty by converting it all into heat, by burning the substance, and measuring the heat produced. Various units have been employed in measuring heat, but the one used in this bulletin is the therm.

A therm[a] is the quantity of heat required to raise the temperature of 1,000 kilograms (2,204.6 pounds) of water 1° C. A pound of good anthracite coal would produce heat enough to raise the temperature of about 3,583 kilograms of water 1° C. Conse-

[a] In the nutrition investigations and studies of foods and feeding stuffs made by this Department and by the State agricultural experiment stations, the results, so far as energy or fuel value is concerned, have been expressed in calories. There is consequently a large mass of available data so expressed. The calorie is the amount of heat required to raise 1 kilogram of water 1° C. (approximately 1 pound of water 4° F.). The small size of the unit has made it necessary to use inconveniently large numbers to express the fuel values of foods and feeding stuffs, a difficulty which is obviated by the use of the therm. As the latter unit is equivalent to 1,000 calories, available data, such, for example, as those in Farmers' Bulletin No. 22, can be readily given expression in the new unit. The use of the word therm, with the abbreviation *t.*, has also been proposed as the equivalent of the small (or gram) calorie, but it has not come into general use.

quently, the chemical energy contained in the coal is 3.583 therms per pound. In precisely the same way the amount of chemical energy contained in many feeding stuffs has been measured. The following are the results of a few such determinations:

Chemical energy in 100 pounds.[a]

	Therms.
Timothy hay	175.1
Clover hay	173.2
Oat straw	171.0
Wheat straw	171.4
Corn meal	170.9
Oats	180.6
Wheat bran	175.5
Linseed meal	196.7

Utilization of Energy.

But the value of a fuel depends also upon how much of the chemical energy which it contains can be used. Hard coal contains plenty of energy, but it would not be of much use to run a gasoline engine. Wheat straw contains fully as much chemical energy as corn meal, but much of that energy can not be utilized by the animal machine.

Two causes combine to affect the utilization of the chemical energy contained in feeding stuffs.

First, more or less of the feed escapes from the body unburned. If a coal is of such quality that portions of it drop through the grate unconsumed, and if smoke and combustible gases are carried off through the stack, it is evident that a ton of it will supply far less heat to the boiler than it would if the combustion were perfect. The case of the feeding stuff is similar. Much of even the best feeding stuffs escapes digestion and is excreted in the dung, carrying with it a corresponding quantity of the chemical energy of the feed. More or less incompletely burned material is also contained in the urine, while ruminants, and to a certain extent horses, also give off combustible gases, arising from fermentations in the digestive tract. Thus about 22 per cent of the chemical energy of corn meal and fully 55 per cent of that of average hay has been found to escape in these ways.

Second, as already pointed out, the animal body has to extract its real fuel material from its feed, separating it from the relatively large proportion of useless material which it excretes. To effect this separation requires work and consumes energy, and this energy, of course, is not available for other purposes. The case is somewhat as if the gasoline engine had to distill its own gasoline and separate it from impurities. Moreover, when the animal eats more feed than is

[a] With 15 per cent moisture.

required simply to furnish energy to run its machinery, and hence is able to produce meat or milk, the process of converting the food into suitable forms to store up in the body seems to require a further expenditure of energy.

It is not, then, the total chemical energy contained in a feeding stuff which measures its value as fuel material to the body, but what remains after deducting the losses in the unburned materials of the excreta and the energy expended in extracting the real fuel materials from the feed and transforming them into substances which the body can use or store up. For example, while 100 pounds of corn meal contain, as stated, about 170.9 therms of chemical energy, only about 88.8 therms remain, after all these deductions have been made, to represent the actual value of the corn meal as a source of energy to the organism.

Energy Values of Feeding Stuffs.

While it is a comparatively simple matter to ascertain the total amount of chemical energy contained in a feeding stuff, the determination of the proportion of this energy which the body can actually utilize requires the use of complicated and costly apparatus (respiration apparatus or respiration calorimeter) and the expenditure of much time and labor. While much has been accomplished along this line, vastly more still remains to be done before we can claim to have even a fairly complete knowledge of the energy values of feeding stuffs. At the same time, enough has already been accomplished, chiefly through the investigations of G. Kühn and of Kellner at the Möckern Experiment Station in Germany, since 1882, and in part also by experiments carried on, in cooperation with this Department, by the Institute of Animal Nutrition of The Pennsylvania State College, to demonstrate that the method still generally current of comparing feeding stuffs on the basis of the digestible matter which they contain is seriously erroneous and to furnish the beginnings of a reform.

The last column of the following table contains the energy values of the feeding stuffs, whose composition was given on page 8, computed on the basis of Kellner's investigations. They are what Kellner calls *production values*—i. e., they show primarily the value of these different feeding stuffs for the production of gain in mature fattening cattle. Even for this purpose many of them are confessedly approximate estimates, and still less can they be regarded as strictly accurate for other kinds of animals and other purposes of feeding. Nevertheless, there seems to be reason for believing that they also represent fairly well the relative values of feeding stuffs for sheep at least, and probably for horses, and for growth and milk production as well as for fattening. At any rate, there can be little doubt that they are

decidedly more accurate than the figures which have been commonly used, and we are quite justified in using them tentatively and subject to correction by the results of later experiments.

As regards swine, the matter is far less certain, and it may perhaps be questioned whether the values given in the table are any more satisfactory for this animal than the older ones.

Dry matter, digestible protein, and energy values per 100 pounds.

Feeding stuff.	Total dry matter.	Digestible protein.	Energy value.
Green fodder and silage:	*Pounds.*	*Pounds.*	*Therms.*
Alfalfa	28.2	2.50	12.45
Clover—crimson	19.1	2.19	11.30
Clover—red	29.2	2.21	16.17
Corn fodder—green	20.7	.41	12.44
Corn silage	25.6	1.21	16.56
Hungarian grass	28.9	1.33	14.76
Rape	14.3	2.16	11.43
Rye	23.4	1.44	11.63
Timothy	38.4	1.04	19.08
Hay and dry coarse fodders:			
Alfalfa hay	91.6	6.93	34.41
Clover hay—red	84.7	5.41	34.74
Corn forage, field cured	57.8	2.13	30.53
Corn stover	59.5	1.80	26.53
Cowpea hay	89.3	8.57	42.76
Hungarian hay	92.3	3.00	44.03
Oat hay	84.0	2.59	36.97
Soy bean hay	88.7	7.68	38.65
Timothy hay	86.8	2.05	33.56
Straws:			
Oat straw	90.8	1.09	21.21
Rye straw	92.9	.63	20.87
Wheat straw	90.4	.37	16.56
Roots and tubers:			
Carrots	11.4	.37	7.82
Mangel-wurzels	9.1	.14	4.62
Potatoes	21.1	.45	18.05
Rutabagas	11.4	.88	8.00
Turnips	9.4	.22	5.74
Grains:			
Barley	89.1	8.37	80.75
Corn	89.1	6.79	88.84
Corn-and-cob meal	84.9	4.53	72.05
Oats	89.0	8.36	66.27
Pea meal	89.5	16.77	71.75
Rye	88.4	8.12	81.72
Wheat	89.5	8.90	82.63
By-products:			
Brewers' grains—dried	92.0	19.04	60.01
Brewers' grains—wet	24.3	3.81	14.82
Buckwheat middlings	88.2	22.34	75.92
Cotton-seed meal	91.8	35.15	84.20
Distillers' grains—dried—			
Principally corn	93.0	21.93	79.23
Principally rye	93.2	10.38	60.93
Gluten feed—dry	91.9	19.95	79.32
Gluten meal—Buffalo	91.8	21.56	88.80
Gluten meal—Chicago	90.5	33.09	78.49
Linseed meal—old process	90.8	27.54	78.92
Linseed meal—new process	90.1	29.26	74.67
Malt sprouts	89.8	12.36	46.33
Rye bran	88.2	11.35	56.65
Sugar-beet pulp—fresh	10.1	.63	7.77
Sugar-beet pulp—dried	93.6	6.80	60.10
Wheat bran	88.1	10.21	48.23
Wheat middlings	84.0	12.79	77.65

FEED REQUIREMENTS.

Assuming that the foregoing table represents with a fair degree of accuracy the amount of repair material (protein), on the one hand, and of energy, on the other, which the various feeding stuffs can supply, we still need to know how much of each is required by the bodies of animals of different kinds and kept for different purposes; in other words, we need some formulation of the feed requirements of farm animals.

Requirements for Maintenance.

Since the animal machine can not be stopped when it is not in active use, it requires, as was pointed out on page 9, and as is a familiar fact of experience, a continual supply of food. This amount of food, which is required simply to support the animal, is commonly designated as the "maintenance requirement"—i. e., it is the amount required simply to maintain the animal when it is doing no work and producing nothing. In other words, it is the least amount on which life can be permanently maintained.

The maintenance requirement is naturally greater for a large than for a small animal. Experiment has shown, however, that this increase is not proportional to the weight of the animal, but approximately to the amount of surface which it exposes, so that the large animal requires less food in proportion to its weight to maintain it than does the small one.

The following tables show the amounts of protein and of energy required per head for the maintenance of cattle, sheep, and horses of different weights. The figures given for sheep include a sufficient allowance for the normal growth of wool. No very satisfactory figures for swine are available. It should be understood that strict accuracy is not claimed for these figures, although they are substantially correct. In particular there seems to be reason to believe that the maintenance requirement of fattening animals increases somewhat more rapidly than these tables indicate.

Maintenance requirements of cattle and horses, per day and head.

Live weight.	Cattle.		Horses.	
	Digestible protein.	Energy value.	Digestible protein.	Energy value.
Pounds.	*Pounds.*	*Therms.*	*Pounds.*	*Therms.*
150	0.15	1.70	0.30	2.00
250	.20	2.40	.40	2.80
500	.30	3.80	.60	4.40
750	.40	4.95	.80	5.80
1,000	.50	6.00	1.00	7.00
1,250	.60	7.00	1.20	8.15
1,500	.65	7.90	1.30	9.20

Maintenance requirements of sheep, per day and head.

Live Weight.	Digestible protein.	Energy value.
Pounds.	*Pounds.*	*Therms.*
20	0.23	0.30
40	.05	.54
60	.07	.71
80	.09	.87
100	.10	1.00
120	.11	1.13
140	.13	1.25

Requirements for Growth.

While young animals gain in weight faster than do older ones, a pound of increase in live weight in the young animal contains much more water and less dry matter than in the case of a more mature animal. Moreover, the dry matter in the case of the young animal contains relatively more protein and less fat, as a rule, than in the older one, and fat contains much more chemical energy than protein, the proportion being 1 to 1.67. The consequence is that a gain of 1 pound in live weight represents the storing up of much less energy in the young than in the mature animal, and therefore requires a smaller supply of energy in the food.

Unfortunately no very extensive determinations of the composition and energy values of the increase of live weight in growing animals have yet been reported. The following estimates by the writer, derived from such data as are available, may serve to give a general idea of the requirements per pound of growth of cattle and sheep at different ages, but they can not lay claim to any high degree of accuracy. The figures refer to normal growth, with no considerable fattening.

Estimated energy value of 1 pound of gain in weight by growing cattle and sheep.

Age.	Energy value.
Months.	*Therms.*
3	1.50
6	1.75
12	2.00
18	2.50
24	2.75
30	3.00

The growing animal also requires a sufficient supply of digestible protein for maintenance and to supply material for new growth. No very systematic study of the latter requirement has yet been made, but from the results of a considerable number of practical feeding

trials it is possible to make a fairly satisfactory estimate of the total amounts of digestible protein which should be contained in the rations of cattle and sheep at different ages to insure satisfactory growth. These estimates are contained in the following table. They are expressed in pounds per head and *include the maintenance requirement.* As a matter of convenience, the table also contains the estimated energy values required per head for normal growth, and it thus constitutes a set of approximate feeding standards. In their use the weight rather than the age of the animal should be the controlling factor.

Estimated requirements[a] *per day and head.*

FOR GROWING CATTLE.

Age.	Live weight.	Digestible protein.	Energy value.
Months.	*Pounds.*	*Pounds.*	*Therms.*
3	275	1.10	5.0
6	425	1.30	6.0
12	650	1.65	7.0
18	850	1.70	7.5
24	1,000	1.75	8.0
30	1,100	1.65	8.0

FOR GROWING SHEEP.

6	70	0.30	1.30
9	90	.25	1.40
12	110	.23	1.40
15	130	.23	1.50
18	145	.22	1.60

[a] Including the maintenance requirement.

No satisfactory data for colts are available, while, as noted on page 15, our knowledge of the relative values of feeding stuffs for swine is somewhat deficient.

Requirements for Fattening.

The foregoing data refer to what might be called normal growth, in which the animals are kept in a good thrifty condition, but do not become fat. If any considerable fattening is desirable, somewhat heavier rations must be given in proportion to the amount of gain made, because the increased gain in fattening animals consists to a very large extent of fat, and therefore means the storing up by the animal of more reserve energy. For fairly mature fattening animals—such, for example, as the 2 to 3-year-old steers which are commonly fattened in the corn belt—probably 3.5 therms per pound of gain in live weight is a fair allowance, although more appears to be often used in practice. As yet no corresponding data are available for the fattening of growing animals, as, for example, in the production of the so-called "baby beef." It is not probable, however,

that any larger amount of protein is required in such fattening than in feeding simply for normal growth, so that the additional food given for fattening may, from this point of view, consist largely of nonnitrogenous material, i. e., carbohydrates and fats. It is to be noted, however, that an excess of these materials in the ration tends to cause less perfect digestion, and also that a moderate proportion of the more nitrogenous concentrates seems to aid in securing the consumption of heavy rations. Kellner recommends that at least 1 pound of digestible protein be supplied in the ration for each 8 to 10 pounds of carbohydrates and fat.

Requirements for Milk Production.

Of all forms of animal production that of milk is perhaps the most variable and most influenced in its amount by the feed supply. The energy relations of milk production have not been very fully investigated. Tentatively, however, it seems safe to estimate that the production of 1 pound of average milk, containing about 13 per cent of total solids and 4 per cent of fat, will require approximately 0.3 therm of production value in the feed. Naturally this amount would vary with the quality of the milk, milk rich in fat and in total solids requiring more than milk containing more water or a lower percentage of fat.

The matter of the protein requirements for milk production has not been altogether cleared up. It seems to have been pretty well demonstrated that, for a time at least, milk production may be kept up on a supply of protein very slightly exceeding that found in the milk produced (of course, in addition to the maintenance requirement). In the case of average milk, this would call for about 0.032 pound of digestible protein for each pound of milk. It has not been demonstrated, however, that a cow can keep this up indefinitely. Furthermore, for the production of liberal yields of milk more protein seems to be required, or at least to be advantageous. No definite statement can be made at present as to how large an excess is necessary. For the ordinary commercial dairyman, however, it is believed that an allowance of 0.05 pound of digestible protein per pound of milk will prove ample.

Requirements for Work.

Since the horse (or mule) is the usual working animal in the United States, consideration will be limited to this animal.

There is on record a considerable amount of data as to the relation between the work performed by the horse and the amount of energy necessary to be supplied in the feed. Where large numbers of horses are kept and the work is relatively uniform in amount, it is possible to make fairly satisfactory computations from these data,

although the method is somewhat complicated. The amount of work required of farm horses, however, is so varied in amount and kind and so difficult of measurement or estimate as regards amount, that it is scarcely practicable to base the calculation of rations upon it. The table on page 15 probably shows with at least a fair degree of accuracy the relative values of different feeding stuffs as sources of energy for work production, while the amount to be fed will ordinarily be based upon the observation of the feeder rather than upon arithmetical calculations. As a sort of general average, however, Kellner recommends the following rations for a 1,000-pound horse, the amounts stated including the maintenance requirement:

Requirements of the working horse.

	Digestible protein.	Energy value.
	Pounds.	*Therms.*
For light work	1.0	9.80
For medium work	1.4	12.40
For heavy work	2.0	16.00

Dry Matter in Rations.

The total volume of feed which an animal requires, although rather variable, has its limits. In computing rations the most convenient indication of the bulk of the feeds is the percentage of dry matter shown in the first column of the table on page 15. In very general terms it may be said that a 1,000-pound ruminant should be given from 20 to 30 pounds of dry matter per day, 25 pounds being perhaps a fair average, while for the horse smaller amounts will be appropriate.

A study of the table shows that concentrated feeding stuffs contain much more protein and energy in proportion to their dry matter than do the forage crops. Evidently, then, in heavy feeding, where the purpose is to give the animal all the feed possible, the ration should consist as largely as practicable of concentrated feeding stuffs, because only in that way can the required amount of food be obtained without unduly increasing the bulk of the ration. On the other hand, in light feeding the coarse fodders may predominate, because they are usually relatively cheaper and can supply the required amount of food in a bulk which the animal can consume.

THE COMPUTATION OF RATIONS.

GENERAL CONSIDERATIONS.

In the foregoing pages we have considered the requirements of the animal machine for repair material (protein), and for fuel material (energy), and have also studied the food as a source of these two. If we knew exactly the requirements of the animal in any given case, and if we knew exactly what amounts of protein and energy the feeding stuffs at our disposal could furnish, the computation of a ration would be almost purely a matter of arithmetic. We would simply have to devise a mixture of the feeding stuffs which would yield the requisite amounts of protein and energy and would at the same time be of suitable bulk and of such a character as to exert no injurious action upon the animal.

As a matter of fact, we have no such exact knowledge. Practically, animals vary in their requirements, while feeding stuffs of the same name show a wide range in composition, digestibility, and nutritive value. Furthermore, what is still more important, the economic conditions vary from case to case so that, for example, a very liberal ration might be advisable in one instance, while for the same animal under different conditions it would be highly uneconomic. The figures given on previous pages can not be made the basis of infallible recipes which shall save the user the trouble of observing and thinking.

But notwithstanding all this, the foregoing data can afford valuable aid to the feeder. By their use he can get a general idea of the feed requirements of his animals and can compute a ration which will approximately supply the requisite amounts of protein and energy. His ability as a feeder will be shown, first, in his power to estimate the conditions which will modify the feed requirements of his particular animals and cause his feeds to vary from the average, and, second, in the skill with which he can interpret the daily results and modify his feeding in accordance with them.

The problems given on the following pages are intended simply as illustrations of the method of using the tables and not as model rations. Limitations of space forbid the multiplication of examples, but the reader who grasps the method will have no serious difficulty in applying it to his own conditions, while facility will be acquired with surprising rapidity by practice. It will be observed that the form of these tables and the methods of computation do not differ materially from those which have been used for many years in computing rations on the basis of "digestible nutrients," although the significance of some of the figures is different. It may be added that

the digestible protein in the tables is true protein—that is, it does not include the so-called "amids" of the "crude protein." Consequently the percentages, as well as the amounts estimated in the rations on succeeding pages, are somewhat smaller than in the older tables.

TOTAL FEED REQUIRED.

A bunch of "feeders" 2 to 3 years old, averaging 1,000 pounds per head, are to be fattened on clover hay and corn-and-cob meal. Such cattle, if of good grade, should weigh 1,400 pounds each when ready for market and should not require over two hundred days to make the gain of 400 pounds. They should therefore make an average gain of 2 pounds per day.

On page 18 it was estimated that a gain of 1 pound live weight requires about 3.5 therms energy value in the feed; for a daily gain of 2 pounds, therefore, the energy requirement would be 7 therms. To this must be added the maintenance requirement, which will increase as the animals grow heavier. For the average weight of 1,200 pounds it is sufficiently accurate to use the maintenance requirement computed in the table on page 16 for 1,250 pounds, viz, 7 therms. This makes the total energy requirement per day 14 therms on the average of the whole feeding period.

If we assume that 2 pounds of grain will be fed for each pound of hay, it is easy to compute from the figures in the last column of the table on page 15 the amount of feed required to supply 14 therms of energy, as follows:

	Therms.
In 100 pounds of clover hay	34.75
In 200 pounds of corn-and-cob meal	144.10
In 300 pounds of feed	178.85
In 1 pound of feed	.596

To supply 14 therms requires $14 \div 0.596 = 23.49$ pounds of total feed, consisting of 7.83 pounds of clover hay and 15.66 pounds of corn-and-cob meal, or, in round numbers, 8 pounds of hay and 16 pounds of meal.

This, of course, represents the average ration for the whole feeding period. At the beginning the feed will naturally be lighter and consist to a larger extent of hay, while the amount of feed, and especially the proportion of grain, will be gradually increased until toward the end of the feeding the animals are consuming all the grain they will take, with only enough hay to insure the necessary bulk and proper digestion. Naturally, too, the form in which the corn is given will usually be varied in the course of the feeding.

IMPROVEMENT OF A RATION.

In the foregoing example it was assumed that the feeding stuffs to be used had been decided upon and attention was directed simply to the quantity required. Let us now take up the question from the other end and see whether a study of the ration may not yield some suggestion of possible improvement.

According to the table on page 15, clover hay and corn-and-cob meal, respectively, contain in 100 pounds—

Feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Clover hay	84.7	5.41	34.74
Corn-and-cob meal	84.9	4.53	72.05

The 8 pounds of clover hay in the ration will evidently contain eight one-hundredths of the amounts given in the table, viz:

84.7 ×0.08=6.78 pounds of dry matter.
5.41×0.08=0.43 pound of digestible protein.
34.74×0.08=2.78 therms of energy value.

A precisely similar computation for the corn-and-cob meal gives the following results:

84.9 ×0.16=13.58 pounds of dry matter.
4.53×0.16= 0.72 pound of digestible protein.
72.05×0.16=11.53 therms of energy.

Adding these amounts, we find that the total ration contains:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Clover hay, 8 pounds	6.78	0.43	2.78
Corn-and-cob meal, 16 pounds	13.58	.72	11.53
Total	20.36	1.15	14.31

The quantity of energy, of course, corresponds with that estimated to be necessary, because the amounts of feed were fixed upon on that basis. We observe, however, that the amount of digestible protein in the ration is considerably less than is estimated on page 18 to be needed by cattle of this age. A ration like the above might produce fair gains, but it would fail to take full advantage of the capacity of such cattle, for growth and the gain would most likely fall below that which was anticipated. An increase in the protein could be expected to make the ration more efficient. One way of accomplishing this which naturally suggests itself is to feed more clover hay, since it is richer in protein than the meal. This would make the ration more bulky, and the rather low total for dry matter indicates that a moderate increase in this direction is practicable. In the early stages of

fattening in particular, at a time when we may suppose that the call for protein is greater than at subsequent periods, a freer use of clover hay would usually be practicable, as well as desirable on the score of economy. Even if we suppose the proportion of hay and grain reversed, however, and the ration to consist for a time of 16 pounds of hay and 8 pounds of meal the digestible protein is after all only slightly increased.

	Pounds.
16 pounds of clover hay contain of digestible protein	0.86
8 pounds of corn-and-cob meal contain of digestible protein	.36
Total digestible protein	1.22

To make any marked change in the ration in this respect, it is evident that we must introduce into it some feed much richer in protein than either of those composing it. On consulting the table it is evident that what we need is one of the by-product feeds like gluten feed or meal, the oil meals, etc., and also that only a small amount of one of these will be needed to effect a marked change in the ration. Thus, if we substitute 2 pounds of old-process linseed meal for 2 pounds of the corn-and-cob meal, the ration will foot up as follows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Clover hay, 8 pounds	6.78	0.43	2.78
Corn and-cob-meal, 14 pounds	11.87	.63	10.09
Old-process linseed-meal, 2 pounds	1.82	.55	1.58
Total	20.47	1.61	14.45

Thus at a comparatively small additional expense we are able to improve the ration materially by adding the lacking protein, and there is little doubt that the improved ration would produce a more rapid gain and, under ordinary conditions, a more profitable one as well, either by increasing the total gain or shortening the feeding period.

COMPUTING A RATION FROM GIVEN FEEDING STUFFS.

There are available for a dairy herd field-cured corn forage (including the ears), clover hay, corn meal, wheat bran, and gluten feed. The table on page 15 shows that these feeding stuffs, if of good average quality, will furnish in 100 pounds:

Feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage	57.8	2.13	30.53
Clover hay	84.7	5.41	34.74
Corn meal	89.1	6.79	88.84
Wheat bran	88.1	10.21	48.23
Gluten feed	91.9	19.95	79.32

The cows average 850 pounds per head and have produced in previous years an average of 20 pounds of milk per day. According to the table on page 16, the maintenance requirement of such animals per day and head would be approximately—

Digestible protein ....pound..	0.45
Energy ....therms..	5.60

For the production of 20 pounds of milk of average quality there would be needed, according to the estimates on page 19:

Digestible protein (0.05×20) ....pound..	1
Energy (0.3×20) ....therms..	6

The total feed requirements per day and head are therefore:

	Digestible protein.	Energy value.
	Pounds.	*Therms.*
For maintenance	0.45	5.60
For milk production	1.00	6.00
	1.45	11.60

The problem, then, is to find a mixture of the available feeding stuffs which will yield these amounts of digestible protein and of energy and which shall have a suitable bulk.

The first step in the construction of a ration is to fix upon the amounts of coarse fodders. It is usually desirable to use as large a proportion of these as possible, since they are usually cheaper sources of food than grain. On the other hand, the amount of them which an animal can consume is limited. Much depends upon the individual animals, and the proper amount can only be told by trial, but we should probably aim to get from 12 to 14 pounds of dry matter in the form of coarse fodder. Corn forage being a cheap feeding stuff, we shall naturally use this freely, with probably some hay for variety. By a little trial, we find that 14 pounds of corn forage and 6 pounds of clover hay will give us 12 pounds of dry matter and the amounts of digestible protein and of energy shown below:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy. value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage, 12 pounds	6.94	0.26	3.66
Clover hay, 6 pounds	5.08	.32	2.08
Total	12.02	.58	5.74

To this we have to add sufficient grain to bring the ration up to the requirement. The proper amount we must ascertain by trial. We

will take, at a venture, 5 pounds of corn meal and 2 pounds of wheat bran. Adding this to the ration we have:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage, 12 pounds	6.94	0.26	3.66
Clover hay, 6 pounds	5.08	.32	2.08
Corn meal, 5 pounds	4.46	.34	4.44
Wheat bran, 2 pounds	1.77	.20	.96
Total	18.25	1.12	11.14

Comparing these totals with the requirement as computed, we find that the ration is slightly deficient in energy and considerably so in digestible protein, while the rather low figure for dry matter shows that more feed may be added to it if desirable. Of the feeding stuffs available, gluten feed is the one richest in protein, and we naturally use this to make up for the lack of this material. We still need 0.33 pound of digestible protein in the ration, and this will be almost exactly supplied by 1½ pounds of gluten feed. Making this addition, the ration stands thus:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage, 12 pounds	6.94	0.26	3.66
Clover hay, 6 pounds	5.08	.32	2.08
Corn meal, 5 pounds	4.46	.34	4.44
Wheat bran, 2 pounds	1.77	.20	.96
Gluten feed, 1½ pounds	1.38	.30	1.19
Total	19.63	1.42	12.33

This ration contains almost exactly the desired amount of digestible protein, but it supplies a surplus of energy which would probably tend to fatten the cows rather than to cause any marked increase in the milk flow. We wish, therefore, to reduce the energy content while retaining the same amount of protein. We can do this by taking out some material, such as corn meal, which supplies chiefly energy, and substituting for it a smaller quantity of some substance like gluten feed, rich in protein. Thus, exchanging 1 pound of corn meal for one-half pound of gluten feed gives us a ration which agrees very closely with the computed requirements:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage, 12 pounds	6.94	0.26	3.66
Clover hay, 6 pounds	5.08	.32	2.08
Corn meal, 4 pounds	3.56	.27	3.55
Wheat bran, 2 pounds	1.77	.20	.96
Gluten feed, 2 pounds	1.84	.40	1.59
Total	19.19	1.45	11.84

This ration corresponds with the average requirement of the whole herd, since it is based on its average performance. It hardly need be said that it should be modified to suit the requirements and capacities of the individual cows, the heavy milkers getting more and the lighter ones less.

By proceeding in this manner, with a little patience we can usually get a ration corresponding as closely as is necessary to the requirement, provided the feeds available admit of it. With a little experience one very soon learns to guess pretty closely, and with some practice finds the computations very easy. An exact agreement with the requirement need not be sought for, since in practice the composition of the feeds will probably vary more or less from the average of the tables.

THE CHOICE OF FEEDING STUFFS.

When, as in the last example, feeding stuffs must be purchased in order to get the desired relation between the protein and the energy of the ration, it is evident that often a wide range of choice may be offered. In such a case the question at once arises which of the various feeds available is it most economical to purchase, it being evident, of course, that this is not necessarily the one offered at the lowest price.

No simple method of determining this point is possible, because, as we have seen, the food serves two entirely distinct purposes in the body. Sometimes the supply of protein is the specially important point, and in other cases what is needed is a supply of energy without special reference to whether its source be protein or nonnitrogenous material. Consequently, the relative values of two feeding stuffs may vary under different circumstances. Some writers have based their comparisons of the values of by-product feeds solely upon their content of protein, for the reason that such feeds are often bought especially to supply this ingredient, while the fats and especially the carbohydrates are usually produced in abundance upon the farm. They regard that purchased feeding stuff as the most economical which furnishes a pound of digestible protein at the lowest cost, ignoring any value in the other ingredients. It is obvious, however, that this is a one-sided view. The other ingredients have a value, and this is especially true in the case of a feeder who buys a considerable part of his grain supply and depends upon it as a source of energy as well as of protein. The method of comparison illustrated in the following pages is based primarily upon the cost per unit of energy because this is on the whole the most important function of the feed, but the method takes account also of the amount of protein present.

Let us suppose the following feeding stuffs are available to a dairyman at the prices named:

Prices of feeds per ton.

Oats (40 cents per bushel)	$25
Corn meal	25
Wheat bran	21
Wheat middlings	24
Dried brewers' grains	23
Gluten feed	27
Cotton-seed meal	30
Old-process linseed meal	33

The supply of coarse feed on the farm is sufficient to furnish each animal per day 32 pounds of silage and 8 pounds of clover hay; the cows average 1,000 pounds each and may be expected to produce about 24 pounds of milk per day.

The first step is to compute, in precisely the same way as in the previous example, the estimated requirements of these cows per day as follows:

	Digestible protein.	Energy value.
	Pounds.	*Therms.*
For maintenance	0.50	6.00
For 24 pounds of milk:		
Protein 24×0.05	1.20	
Energy 24×0.30		7.20
Total requirement	1.70	13.20

The amounts of silage and clover hay available will furnish, according to the table on page 15, the following amounts of dry matter, digestible protein, and energy value:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pound.*	*Therms.*
Corn silage, 32 pounds	8.19	0.39	5.30
Clover hay, 8 pounds	6.78	.43	2.78
Total	14.97	.82	8.08

The question now is what feeding stuffs is it most economical to buy (or to refrain from selling if in stock) to complete the ration. The first step in deciding this question is to compare the various feeds as sources of energy and see which one furnishes a unit of energy

value at the lowest price. This computation gives the following results:

Kind of feed.	Cost of 100 pounds.	Energy value of 100 pounds.	Cost of 1 therm energy value.
		Therms.	*Cents.*
Oats	$1.25	66.27	1.89
Corn meal	1.25	88.84	1.13
Wheat bran	1.05	48.23	2.18
Wheat middlings	1.20	77.65	1.55
Dried brewer's grains	1.15	60.01	1.92
Gluten feed	1.35	79.32	1.70
Cotton-seed meal	1.50	84.20	1.78
Old-process linseed meal	1.65	78.92	2.09

Evidently, if it were simply a question of supplying energy to the animals, we should use corn meal, since that supplies a unit of energy at a much lower price than any of the other feeding stuffs. If it were thought desirable to add variety to the ration, wheat middlings would obviously be our next choice.

It is evident, however, without going through the labor of computation, that while corn meal and wheat middlings may be used in the ration, neither will supply enough protein if used exclusively. Of the available feeding stuffs which are rich in protein and which may therefore serve to balance the deficiency of this ingredient, gluten feed is relatively the cheapest, and cotton-seed meal comes next. While the difference between the two is not great, we shall naturally try the cheaper one. It is not difficult to determine by a few trials that 4 pounds of corn meal and 2½ pounds of gluten feed, in addition to the coarse fodder available, will give a ration corresponding very closely to the requirements, as the following table shows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn silage, 32 pounds	8.19	0.39	5.30
Clover hay, 8 pounds	6.78	.43	2.78
Corn meal, 4 pounds	3.56	.31	3.55
Gluten feed, 2½ pounds	2.30	.50	1.73
Total	20.83	1.63	13.36

This ration shows as close an agreement with the computed requirement as could be desired. The comparatively low figure for dry matter indicates that more coarse fodder might have been used had it been available, with the probable effect of cheapening the ration. As it is, we have used the feeds relatively lowest in price and apparently have a very economical ration.

Since, according to the assumed figures, corn meal is relatively cheap as compared with the other feeding stuffs, we shall naturally try to use as large a proportion of this in the ration as practicable. In order to increase the corn meal, however, it will plainly be necessary to use some other feed richer in protein than gluten feed. Cotton-seed meal is nearly as cheap as a source of energy as gluten feed, while it contains almost twice as much protein. We therefore try the effect of increasing the corn meal to 4½ pounds and using 1½ pounds of cotton-seed meal in place of the 2½ pounds of gluten feed, with the following results:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn silage, 32 pounds	8.19	0.39	5.30
Clover hay, 8 pounds	6.78	.43	2.78
Corn meal, 4½ pounds	4.01	.31	4.00
Cotton-seed meal, 1½ pounds	1.38	.54	1.26
Total	20.36	1.67	13.34

This ration agrees with the computed requirements even better than the previous one, while a simple comparison shows that it is actually a trifle cheaper. The grain portion of the two rations costs as follows:

Feed in ration.	First ration.	Second ration.
	Cents.	*Cents.*
Corn meal	5.00	5.63
Gluten meal	3.37	
Cotton-seed meal		2.25
Total	8.37	7.88

It thus appears that a ration made up with the somewhat more expensive cotton-seed meal was actually cheaper because it was possible to use more of the cheap corn meal. The difference, to be sure, is small, yet for 30 cows fed for 200 days, it would amount to $30. Such a difference is only likely to be found, however, when, as was assumed in this instance, some feed low in protein but rich in energy can be had at a relatively cheap rate. In general, it may be said that when there are no very marked differences in the cost of a therm of energy value in the feeding stuffs constituting the bulk of the ration one of the various high-protein feeds which supplies energy at the lowest cost should ordinarily be used, although it is always wise to check up this point, as in the example just given.

THE COMPOUNDING OF RATIONS.

While in the foregoing examples an exact daily ration is computed, it would, of course, be utterly impracticable in most cases to weigh out separately each day's ration for each animal. Individual weighings of feeds at intervals would often yield valuable information and might be profitably undertaken, but for the ordinary routine of feeding simpler methods must be used.

When practicable, the grain feed may be advantageously mixed in advance in the desired proportions in as large quantities as the storage capacity available and the proper preservation of the materials will permit. Where facilities are available, the whole amount of grain required for all the animals may be weighed out daily, or even for each feeding, without much additional labor. In distributing the grain to the individual animals, regard of course should be paid to their productive capacity and their individual peculiarities. The ration, as computed, is for the average animal. The skill of the feeder is shown in adapting it in quality and in amount to the individual. Doubtless individual weighings at intervals, as already suggested, would be useful as a control on the accuracy of the distribution.

The weighing of coarse fodder is usually a more difficult problem on account of its bulk. When, however, silage or cut fodder is handled in trucks, the matter is still comparatively simple. Long fodder, on the contrary, is not readily weighed. Nevertheless, even here an occasional weighing, if practicable, as a control upon the feeding, is very desirable.

In all these and similar matters common sense is necessary. The computed ration expresses the best estimate that can be made of the actual average requirements, but it is at best more or less of an approximation. It would be foolish, therefore, to seek extreme exactness in realizing it or to go to more expense in the weighing and apportioning of the feed than the saving in the latter would amount to. The scale upon which the feeding is conducted will play an important part. Where scores or hundreds of animals are being fed, an exactness may be profitably sought which would be absurd in the case of two or three animals. Finally, it should be remembered that these computed rations are guides and not recipes. They may aid the feeder in wisely using the resources at his command, but they can not take the place of experience and good judgment.

BEARING ON FARM MANAGEMENT.

The data and the methods of computation on previous pages will aid the feeder in determining the amounts of each class of feeds needed for each class of his animals. The man of good business habits will find them useful in determining the quantities of each kind of feed to grow or purchase and in deciding upon the purchase of animals to feed and the feeds to keep or to purchase for feeding them. These facts and methods will aid the farmer, the feeder, or the user of work animals in deciding upon the chances of profit in proposed enterprises. Often by using these formal ways of checking up a proposed business project the way is made more clear to avoid loss and to secure the largest practicable profit. In case of the farmer who grows most of his feed stuffs, these facts and methods of calculation may often be used in connection with the planning of his scheme of crop rotation and in proportioning the acreages of the respective crops to each other and to the numbers of each class of animals. They will prove useful in reducing the farm-management plan to a scientific basis.

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